SOIL HETEROGENEITY ASSOCIATED WITH DESERT TREES AND SHRUBS GROWTH AT ELKABASHI AREA, NORTH OF KHARTOUM, SUDAN

By

Sulieman Hammad Nasser Ali

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Faculty of Agriculture

University of Khartoum

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Supervisor

Professor Yousif ElGorashi ElMahi

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DEDICATION

To my father

Mother

Sisters, brothers and their families

To the soul of my brother Siddig and his family.

I dedicate this work.

Sulieman

ACKNOWLEDGEMENT

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ABSTRACT

Soils near Khartoum, Sudan, found under the crown of acacia (*Acacia tortilis*) and capparis (*Capparis decidua*) trees were compared at three depths to those collected from between the trees and from adjacent openings with respect to several physical, chemical, and biological properties.

Trees had significant impacts on the physical, chemical, and biological properties of the soil. Analysis of variance showed that location main effect (canopy or open) differed significantly for all properties tested except pH, soil texture, moisture content and saturation percentage. Many characteristics examined varied with depth, with the exception of soluble K, Ca, and Mg, which increased, significantly with depth.

Total nitrogen and 0.5 M $NaHCO_3$ extractable phosphorus in soil under acacia canopies were about two times greater in the (0-30 cm) layer than those in the same layer in the open and between the trees and vice versa in capparis tree site. There were significant differences in C/N ratios and in the soluble cations and anions among locations. There were also significant differences in plant density and fungal numbers among locations.

Aggregate stability was higher under trees than interspace and openings and was highest under capparis tree. There was s generally a significant correlation between organic matter percentage and aggregate stability ($r^2 = 0.45$).

Results suggest that leguminous trees improve soil conditions under their canopies by redistribution and consequent concentration of ions from areas beyond the canopy or from sub soil to surface soil beneath the canopy.

ملخص الاطروحة

تمت مقارنة الترب تحت غطاء اشجار السلم والطندب بالترب التي بين الاشجار وفي المنطقة الخالية من الأشجار لاعماق مختلفة لدراسة بعض خواص التربة الفيزيائية الكيميائية ، والحيوية في منطقة الكباشي شمال مدينة الخرطوم.أوضحت النتائج أن للاشجار تأثيرآ معنويآ علي بعض الخواص الفيزيائية ، الكيميائية ، والحيوية للتربة. ولقد اظهر التحليل الإحصائي أن هنالك فرقآ معنويآ للموقع – الأثر العام-(للأشجار أو في المنطقة الخالية من الأشجار) في كل الخصائص قيد الدراسه عدا تفاعل التربة ، و المحتوي الرطوبي ، وقوام التربة، ونسبة التشبع. وتباين تأثير الموقع في عدد من الخصائص التي تمت دراستها نتيجة للعمق عدا البوتاسيوم ، الكالسيوم ، الماغنيسيوم ، وتفاعل التربة التي زادت قيمها معنويآ مع العمق.

أما النيتروجين الكلي، والفسفور المستخلص بواسطة بيكربونات الصوديوم (M 0.5) في العمق (0– 30 سم) تحت غطاء السلم فقد زادت حوالي ضعفي التركيز في المنطقة الخالية من الأشجار لنفس العمق، وكانت النتائج عكس ذلك في حالة الطندب. هنالك فرق معنوي في نسبة الكربون إلي النيتروجين بين المواقع. كما لوحظت اختلافات معنوية احصائيآ بين المواقع في تركيز الكاتيونات والأنيونات الذائبة.هنالك اختلافات معنوية في كثافة النباتات وعدد الفطريات بين المواقع.

ثبات الحبيبات كان اعلي تحت الأشجار مقارنة بالمواقع بين الاشجار وفي المنطقة الخالية من الاشجار، وكانت القيمة اعلي تحت الطندب عنها تحت السلم. وعموما كان هنالك ارتباط معنوي($r^2 = 0.45$) بين المادة العضوية وثبات الحبيبات.

أظهرت النتائج ان أشجار السلم تلعب دورا مهما في تحسين ظروف التربة التي تحت غطائها باعادة توزيع الأيونات من التربة العميقة أو المنطقة خارج غطائها إلي التربة السطحية التي تقع تحت الغطاء.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
UL	Under leguminous tree
BL	Between leguminous tree
OL	Open leguminous tree
UNL	Under non- leguminous tree
BNL	Between non-leguminous tree
ONL	Open non-leguminous tree

Chapter One

INTRODUCTION

Arid and semi-arid land covers approximately one third of the continental surface of the earth (Dregne, 1976). They include the deserts and their arid, semi-arid and dry sub-humid margins, and the sub-tropical Mediterranean latitudes. The semi-arid ecosystem provides important land resources for adapted agricultural production and grazing systems.

The status of dry land systems is controlled to a large extent by a fragile equilibrium between soil, vegetation and water resources. Precipitation rates are generally low and rainfall events are known to be irregular and of high intensity, with prolonged periods of high temperature, high evapotranspiration rates and low relative humidity. Natural ecosystem and traditional land use practices have adapted to these conditions overtime, on the assumption of optimum use of available resources.

Dry land degradation may be triggered by (global) climatic change and / or human mismanagement. While the former may result in more frequent drought events, the latter is mainly caused by inappropriate land use. Both may include changes in surface soil properties, thereby affecting the type and density of the vegetation cover.

In the Sudan dry lands are confined between latitude 12ºN and 22ºN, under different climatic zones: hyper arid, arid, semi-arid and dry sub-humid (Fadul and Gani, 2000). These climatic zones have pronounced effect on the biological diversity and soil. In the hyper arid climatic zones no vegetation exists except along the fertile

sediments of the banks of the channels of seasonal water. In arid climatic zones, vegetation is sparse and the dominant land utilization types are grazing and irrigated agriculture. The semi-arid lands support grazing and rainfed agriculture.

The soils of the dry land, especially north of latitude 16°N, are characterized by low fertility, low organic matter, alkaline reaction and accumulation of $CaCO_3$ in the sub soil (various Soil Survey Reports, Soil Survey Administration Wad Medani, Sudan). The main soils are Aridisols (with pockets of Vertisols), which are inherently low in total nitrogen (300 ppm) and urea is commonly used for irrigated agriculture. The Entisols of the recent Nile sediments are very fertile, while Entisols of the sandy areas are very low in fertility (Fadul and Gani, 2000).

Plant growth and production in arid and semi-arid zones is primarily limited by water availability and the ability of the plants to optimally utilize this limited resource. Nutrient and water availability for grasses and herbs in such environments are also strongly linked to nutrient cycling and modification of soil moisture condition by small desert trees and shrubs.

Desert shrubs develop what is known as “islands of fertility”, that is, zones of increased nutrient availability and improved soil moisture conditions below and immediately surrounding each individual plant (Garner and Steinberger, 1989;Charley and West, 1975; Barth and Klemmedson, 1978). In such ecosystems, improvements in soil fertility can result directly from the presence of the shrub and its influence on nutrient cycling and redistribution of nutrients (Charley and West, 1975; Barth and Klemmedson, 1978) and /or water within the soil profile (Van Miegroet *et al*., 2000). Indirect plant effects occur through shading and / or by creating a favorable

environment for microbes and other organisms such as earthworms, due to greater litter accumulation, which in turn stimulates decomposition and ultimately results in greater nutrient availability.

Little work, if any, is performed in the Sudan to study this phenomenon; therefore, this research work aims:

1. To compare some soil physical properties such as texture, aggregate stability, saturation percentage and moisture as well as some chemical properties of tree fertility islands with their surrounding meadows in an arid zone location north of Khartoum.
2. To investigate some of the tree fertility islands' biological properties, which may affect soil fertility.
3. To compare the impact of tree species on the above mentioned physical, chemical and biological soil properties.

Chapter Two

LITERATURE REVIEW

2.1. Global Extent of the arid regions

Arid and semi-arid ecosystems occur in many continents, occupy almost one third of the earth's terrestrial surface, and are inhabited by millions of people.

Scarcity of precipitation is the dominant characteristic of the arid regions of the world. Dryness is not due solely to a lack of precipitation; it is influenced strongly by temperature, humidity, wind and seasonal distribution of rain. Arid region soils posses many unique characteristics that distinguish them from their more well-known counterparts in humid regions. They commonly have a low level of organic matter, slighty acid to alkaline reaction (pH) in the surface, calcium carbonate accumulation some where in the upper five feet of soil, weak to moderate profile development, coarse to medium texture, and low biological activity (Dregne, 1976).

2.2 Dry lands in Sudan

Dry lands in Sudan are confined between latitudes 12ºN and 22ºN under different climatic zones viz-hyper arid, arid, semi- arid and dry sub-humid. These climatic zones have pronounced effect on biological diversity and soil. (Fadul and Gani, 2000).

2.3 Effect of vegetation on soils

The role of vegetation in improving the environmental conditions is becoming increasingly appreciated. It is believed that vegetation can positively influence the global climatological conditions. (Young, 1986).

The role of vegetation in soil formation and fertility has been acknowledged by soil scientists. The major effects of plants are due to the addition of organic matter from the former to the latter (Young, 1986). Different plant communities do not contribute equal amounts of litter to the soil. Quantities of litter added to soil depend on the type of vegetation (Fitzpatrick, 1986). Soil content of organic matter does not solely depend on the quantities added, but as well on the rate of the decomposition and consumption by soil organisms.

On the basis of knowledge gathered from tree species, Tiedemann and Klemmedson, (1973) reported that absorption of soil moisture by lateral tree roots is expected to be accompanied by absorption of nutrients. The nutrients are translocated to various parts of the tree, incorporated in plant biomass, and are eventually returned to the soil when leaves, twigs, and other plant parts are shed. The bulk of this material falls directly beneath the tree canopy. This process presumbly results in more or less a contrast of depleted nutrient regime and harsh physical condition of the soil in open areas, and a soil enriched by nutrients and organic matter with improved physical and chemical conditions beneath the canopy.

Effects of organic matter on soil physical and chemical properties are well known and were extensively studied by many authors (O'Connels, 1984; Jose and Koshy, 1972; Jha *et al*., 1979). It can influence soil color and improve water retention, structure, exchange capacity, nutrient content, pH …etc. Studies have shown that organic matter represents a considerable source of nutrients to agricultural soils. Moreno *et al*. (1960) found that organic matter may complex Ca and thus increase the concentration of soluble P in the soil.

Plant roots also play very important role in the soil. They can hold the soil mass together through the reticulum of their branching system and thus prevent or lessen soil erosion by wind or torrential rains (Jenik, 1977). Therefore, functions of plant roots can be summarized as:

- They can ameliorate soil structure, aeration and permeability, by binding soil particles together, formation of aggregates, and channels left behind after their death. In addition penetration of water and air into the channels of dead and decayed roots can induce occurrence of many chemical reactions e.g. oxidation and carbonate precipitation (Armson, 1977).
- They constitute an important physical weathering agent when they help to fracture and fragmentize rock and boulders through their growing force (Jenik, 1977).
- They represent a source of organic matter to soils, from their exudates and matter resulting from their death. In this respect, root tips are normally areas of soil fauna and flora eutrophication by feeding from the easily digestible material (polysaccharides, cellulose, soluble tannins…etc), which results from root exudates. Plant roots can also assist in redistribution and homogenization of minerals through their extensive and deep reaching network. In these respects forest vegetation is far more efficient than grass vegetation (Kerfoot, 1963).

A heterogeneous vegetation structure results in the concentration of favourable conditions underneath individual plants, patches or strips.

2.4 Fertility islands

Three decades ago, Charley and West (1975) introduced the term islands of fertility to describe the accumulation of nutrients underneath the canopy of the shrubs in the semi- desert of Utah, USA. Similarly, in a Chiltean desert the concentration of soil nitrogen (N), phosphorus (P) and soil organic matter were higher underneath than outside the canopies of shrubs (Gutierrez *et al*., 1993).

Smaller individuals such as those of the grass species *Bouteloua gracilis* were able to significantly modify the concentration of nitrogen and carbon underneath their canopies (Hook *et al*., 1991). At a coarser scale, the upper soil layer of the mugla groves had higher nitrogen than the inter-groves (Ludwig and Tongway, 1995). Phosphorus, being an element less mobile in the soil, showed similar trends but in the upper most layer only.

There were clear signs of accumulation of nutrients under canopies of acacia. Total N, total and available P, S, organic C, and electrical conductivity increase. (Facelli and Daniel, 2000).

Bolling and Walker (2002) reported that fertile island pattern for total N, available P, and organic matter were more circular than patterns for bulk density, texture or pH. They also suggested that patterns of soil heterogeneity may develop first for elements that may be limiting to desert shrub growth (N, P, and other nutrients released from decomposition of organic matter), followed by spatial development in other less limiting factors (bulk density, texture and pH).

Trees have been shown to have a marked effect on the soils in their immediate vicinity. Results showed higher soil organic matter and nutrient content (e.g. phosphorus and nitrogen) in soils around trees, which diminished with distance from the tree (Wilson, 2002). Zinke (1962) also found that each tree has an influence - circle roughly proportional to the size of the crown area

projection on the soil surface, and that the tree has a maximum influence under the crown canopy and the influence decreases outward from the tree.

Evertt *et al.* (1986) reported that nutrient concentrations were greater under the crowns of trees than in soils between trees.

Garner and Steinberger (1989) stated that fertile island formation was primarily a biological process, whereby plants and animals concentrate mineral nutrients from a wide area to the island and into plant biomass.

Organic matter and pH are spatially variable because of fertile islands (Caldwell and Jackson, 1993), and the availability of N and P increases under shrubs (Romney *et al.*1980; Skujins, 1981). These changes are especially important because N and P are the elements considered most limiting to plant growth in arid regions (Schlesinger *et al.*1996). In a micro scale, soil conditions can change drastically within few centimetres. For example, heterogeneity in N at small scales can be expected because of the susceptibility of NH_4^+ and NO_3^{2-} to local microbial transformations (Caldwell and Jackson, 1993). The highest intensity of microbial activity in the deserts occurs around plant roots (Vollmer *et al.*, 1973; Binet, 1981).

Concentrations of total soil N showed more pronounced patterns around shrubs. Total N, and soil organic matter had higher levels of spatial variation than the other soil parameters measured (excluding N mineralization and soil moisture that may measure temporal variability). Fertile island structure was therefore based mostly on changes in the most variable parameters, viz soil N, P, and organic matter; mycorrhizal fungi probably play a significant role as well (Bolling and Walker, 2002).

Garner and Steinberger (1989) reported that the ultimate causes of fertile island are biological and are affected by shrub processes (growth and subscission of roots and shoots), decomposition, and physical transportation of organic matter by animals.

Schlesinger *et al*. (1996) found that, over the last century, the effects of desertification on New Mexico desert soils included an increase in soil nutrients under shrubs compared to open spaces. They also stated that as shrubs increase in abundance, so did the soil nutrients heterogeneity.

Total N, organic matter and $NaHCO_3$ extractable PO_4^{-3}-P were significantly higher under plant canopy and large amounts of N had accumulated in the surface 30 cm beneath the canopy. The sodium adsorption ratio (SAR) of saturation extracts of 0-30 cm soil samples was significantly lower at the centre of the tree canopies than in soil between trees (Virginia and Jarrell, 1983).

The effects of the species were highlighted by Alban (1982) who reported that aspen and spruce stands accumulated more of most nutrients under canopies than did spine stands.

Charley and West (1977) and Parker *et al*. (1982) showed that N availability was greatest in the surface soil layers below the canopy of dominant shrubs where organic matter accumulates.

Soils under plants had greater total and available nutrient resources with higher concentrations under crestobush than under grasses (Kieft *et al*., 1998).

Desert shrubs and their associated islands of fertility can, thus, result in improvements in soil fertility due to nutrient cycling and redistribution of nutrients (Charley and West, 1975; Barth and Klemmedson, 1978; Garner and Steinberger, 1989; Rostagno *et al*., 1991; Hysell and Grier, 1996) or redistribution of water within the soil profile (Richards and Caldwell, 1987; Caldwell *et al*., 1991).

Nimer (2000) found that *Acacia senegal* in Kordofan induced considerable changes in the soil morphology, physical and chemical

properties: The soil became more differentiated with a third layer clearly discernible. Its organic matter content has been augmented to about one and a half times, deeply incorporated and stained the whole profile with dark hues. The soil reaction became slightly acidic (pH 6.3). The major nutrients (N, P, Ca, and Mg) had generally increased. *Acacia senegal* increased total N, and organic carbon while it had no effect on pH, available P and K of a sand sheet soil (Gerakis and Tsangarakis (1970). Rawanaski and Wickens (1969) showed that soils under *Acacia albida* in Western Sudan were black, moist, well developed with stable crumb structure, and with many roots absorbing water freely. This contrasted the compact, weakly structured, unstable, and liable to sheet erosion soil in the bare land, where there was no tree cover.

Van Miegroet *et al*. (2000) concluded that tree island affected O-horizon mass and chemistry (higher macro nutrients concentrations and lower C/N ratio had accumulated under tree canopies), double that accumulated in the island interior and much less in the meadow. Surface soils inside the tree islands had significantly higher C and N concentrations and higher C/N ratio. The pH of the upper soil below the trees was higher than in the meadow and it decreased with depth. The presence of tree islands significantly modified the soil microclimate and nutrient distribution relative to the surrounding meadow.

On the other hand, Bates *et al*. (2002) found no fertility island effect under the canopy influenced soils with respect to available N under the uncut Juniper woodland.

The tree effects on the soil microenvironment are not only provided from the species variation but also from the position of the

tree canopy. Pandey, *et al*., (2000) reported that the sand particles declined by 10% and 9 % whereas clay particles increased by 14 % and 10 % under mid canopy and canopy edge, respectively. Clay particles did not decline significantly with soil depth under tree canopy. Soil organic carbon, total N and total P were greater under tree canopy compared to open space. Soil organic C, total N pool sizes were maximal in 0-10cm and declined with depth.

2.5 Nitrogen fixation in fertility islands

Incorporation of atmospheric nitrogen into the soil is achieved mainly through two ways:

2.5.1 Non-symbiotic fixation

This is performed by agents living freely in the soil like azotobacter bacteria, and the photosynthetic microbes e.g. blue algae.

2.5.2 Symbiotic N fixation

This is achieved by several agents among which the genus *Rhizobium* sp is the most important one.

Radwanski and Wickens (1969) found that soil nitrogen increased under *Acacia albida* but not under the non-leguminous trees such as *Balanites aegytiaca* and *Guiera sengalensis*. Leguminous plants may fix about 200 pounds or more of nitrogen per acre each year if effective strains of proper root nodule bacteria are present in the soil (Franklin, 1957).

Hague (1992) reported that under acacia trees concentration of P, N and K were much higher as compared to the bare land, while there was no effect on soil pH, Ca, Mg and Na. On the other hand, Reviksumer and Singh (1992) found that the ameliorative effect of

Acacia nilotica was most pronounced on N, organic carbon, P, and Ca contents. Bulk density was also lower under this tree compared to the continuously cultivated land.

On the other hand, populations of organisms are generally much greater in number and diversity under the canopy than in the open space; the favorable environment of the soil under trees simulate the proliferation of a myriad of microorganisms that perform many complex tasks relating to soil formation: slash and litter disposal, nutrients availability and recycling, and metabolism and growth (Williams, 1979 and Smith.*et al*., 1998).

Since, free-fixing microbes are rare in arid environments, and blue – green algae in lichens soil crusts are not always present, nitrogen fixation must, therefore, take place by some kind of association with higher plants, and no more nitrogen has in many cases, been found in the proximity of leguminous than nonleguminous shrubs of similar size and form. Harold and Paulsen (1953) repeated their search on nodules of symbiotic nitrogen-fixing bacteria and it has failed to disclose any differences between leguminous and nonleguminous in the study area. Lack of suitable conditions of temperature and moisture and absence of proper endophyte frequently prevent nodule formation in legumes of arid regions. For deserts there is abundant evidence that nitrogen fixation takes place in association with the roots of many nonlegumes (Farnsworth *et al*., 1976).

Garcia- Moyia and Mckell (1970) stated that the leguminous shrubs appear to serve the same function as non-leguminous shrubs in nitrogen economy, and the importance of shrubs lies more in the way they serve as a reservoir for soil fertility rather than in any significant participation in symbiotic nitrogen fixation.

Chapter Three

MATERIALS AND METHODS

3.1 The study area

The study area (Salamt Elkabashi) is located in a level arid area 23 kilometres to the north of Khartoum North town (15° 51′ 0.547″ N, 32° 34′0.775″E), at an elevation of 383 meter above sea level. The climate is semi-desert with an average annual precipitation of 100 mm. Highest monthly temperature (45˚C) occurs in June and the minimum temperature (13.5˚C) occurs in January as shown in Table (1).

The vegetation in the area consists of sparse annual grasses in the rainy season and scattered bushes predominantly *Acacia tortilis* followed by *Capparis decidua*.

3.2 Methodology

3.2.1 Experimental units

A total of six plots under and around trees, to be called here under "tree islands", were selected at random in the study area. Three of the tree islands were under leguminous (*Acacia tortilis*) and the other three were under non-leguminous tree species (*Capparis decidua)* (Plates 1 and 2). The selected trees were representative of the area in terms of size, height, structure and species composition. All islands consisted of either a treeless centre surrounded by band of tree clusters or of single trees. Characteristics of these tree islands were compared with samples taken from positions between the trees and other samples from the open treeless meadow.

Plate (1): General view of *Capparis deciduas* stand.

Error!

Plate (1): General view of *Acacia tortilis* stand.

3.3.2 Soil sampling and preparation of samples

Number of auger samples were collected from the following depths: 0-30 cm, 30-60 cm and 60-90 cm at each sampling site in the three different sub areas. All soil samples were ground to pass a 2.00 mm sieve and mixed thoroughly; the sieved samples were stored in polythene bags and later used for the determination of some of the physical, chemical and biological properties of the soil.

3.3 Analysis of soil samples

3.3.1 Chemical properties

Soil analysis included soil chemical properties such as soil pH, electrical conductivity of the saturatation extract (ECe), soluble potassium, sodium, calcium and magnesium, and the anions (except extractable SO_4^{2-} that was extracted with $NH4^+$ acetate as specified by Bardsley and Lancaster, (1965)), sodium adsorption ratio (SAR) were determined according to the method described by Chapman and Pratt, (1965). Phosphorus was determined by 0.5 M sodium bicarbonate ($NaHCO_3$) solution at a pH of 8.5, (Olsen *et al*, 1954). Soil organic carbon and nitrogen were estimated using dry combustion (Allison *et al.* 1982) using Vario Max CN Elementar Spectrometer . $CaCO_3$ was determined using volumetric calcimeter method (Allison and Moodie, 1982). Water soluble constituents (Na, K, Mg, and Ca) were extracted following Bower and Wilcox (1965), and measured by Atomic Adsorption Spectrophotometery (UNICAM M series SOLAAR-Atomic Adsorption Spectrometery, type: SOLAAR ID 90 Interface kit).

3.3.2 Physical properties

Soil physical properties were measured included soil moisture content, particle size distribution by the hydrometer method, (Day, 1965) and soil aggregate stability by wet sieving (Kemper and Chepil, 1982).

3.3.3 Microbial study

Fungal numbers were used as an index of biological activity in topsoil samples (0-30 cm). Quantitative measurements of fungal growth were made using plate method of Mitchell *et al*., (1986).

3.4 Vegetation cover

Within each of the sampling area so defined three 0.5 ×0.5 m quadrats were randomly placed, and within each quadrat, the percent cover was estimated.

3.5 Classification of Tree Island Soils

Soil of the studied area was classified as Typic haplocambids (Key to the Soil Taxonomy, 1998).

3.6 Statistical Analysis

Multifactor analysis of variance was performed to estimate the effects of the measured parameters using a two way factorial split block design, with tree species as the main blocks and depths as sub-blocks according to SAS program (version 3) (SAS, 1994). Each sample was analyzed in triplicate and the figures were then averaged. Significance level accepted was $P \geq 0.05$ and means were separated according to Duncan's Multiple Range Test (DMRT) (Steel and Torrie, 1960 and Ott, 1977).

Table (1): Means of the maximum and the minimum temperature and rainfall of the study area in the year 2003.

Month	Max. (C°)	Min. (C°)	Rainfall (mm)
January	29.7	13.5	Nil
February	31.9	16.2	Nil
March	37.3	18.3	T.R
April	41.2	22.7	Nil
May	42.0	25.0	3.1
June	41.3	24.0	Nil
July	37.8	25.5	43.0
August	35.5	25.3	56.9
September	38.9	26.2	18.8
October	39.4	24.5	3.6
November	35.3	21.1	Nil
December	32.6	16.2	Nil

Source: Sudan Meteorological Authority- Khartoum (2003).

Chapter Four

RESULTS

4.1 Physical properties

Soil moisture content (% M.C) and Saturation Percentage (SP) did not change significantly among locations but it changed with depth (Table 2). Increasing soil moisture content was found with depth under the canopies. Percentage aggregate stability (% AG)

varied significantly among the treatments ($P \geq 0.05$). It was higher under the canopies, particularly under *Capparis* sp which was double that of under *Acacia* sp; but there was no significant differences between locations. There was positive correlation between aggregate stability and organic matter percentage ($r^2 = 0.45$). This is depicted from Table (2) and Figure (1) which represents results of simple structured stability test.

Fig. (2) and Table (2) illustrates that soil texture did not change significantly among locations. However, increasing amounts of clay and silt and decreasing of sand were found with depth. There was lack of correlation between % clay and % O.M ($r^2= 0.079$) Fig. (3).

Fig. (1): Correlation between organic matter and aggregate stability.

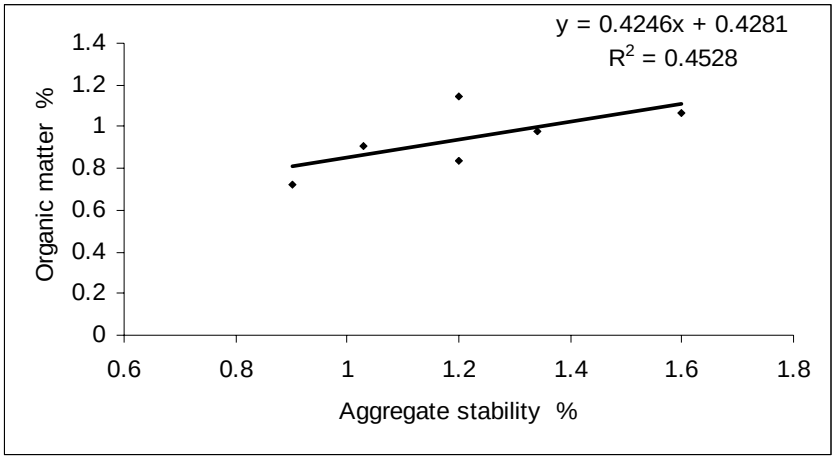


Fig. (2):Means of percentages of soil moisture content (M.C %), saturation percentage (S.P) and soil texture and aggregate stability in the different locations.

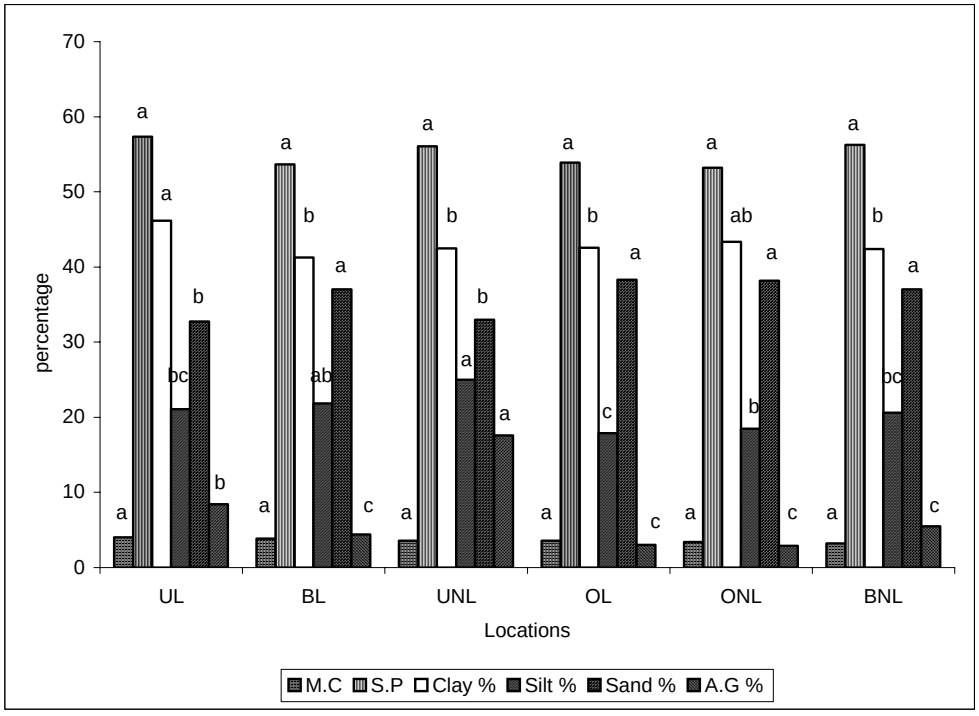
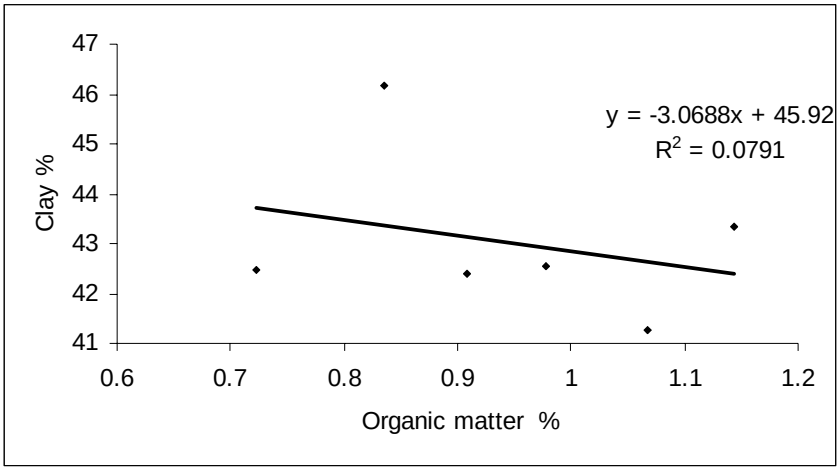


Fig.(3) Correlation between organic matter and clay %.



4.2 Chemical Properties

Soil reaction (pH) differed significantly with depth in all locations, but there were no differences among locations at any depth (Table 3 and Fig 4), the pH readings oscillate around value 7.9.

Organic matter (%O.M), total N, and o.5 M $NaHCO_3$ extrctable P in soil under canopies were two to three times greater in the 0-30 cm layer than in the two lower layers. There were also significant differences ($P \leq 0.05$) among the second and the third layers in the open and between the trees for the same parameters. Approximately two times more organic matter, total N and 0.5 M sodium bicarbonate ($NaHCO_3$) extractable P were found in the 0-30 cm layer under acacia than the same layer in the open and between the trees, and vice versa in the non-leguminous tree.

In contrast to differences observed with total N, 0.5 M $NaHCO_3$ exractable P and organic matter, $CaCO_3$% did not change significantly among locations regardless of the depth.There was, however, a significant decrease, between 0-30 cm and the other two depths (Table 3).

Statistically significant differences in C/N ratio between locations were observed in all depths. Under the surface layer, C/N ratios and their variability tended to increase. When the locations were analyzed separately, soils under the leguminous site had lower C/N ratio (Table 3 and Fig. 5). There was positve correlation between O.M % and C/N ratio ($r^2 = 0.32$) (Fig 6).

Soluble cations and anions also differed between locations and with depths. There were significant differences in K concentration among locations in the non-leguminous tree site, where there was more K in the open location, and no differences were found between the other two locations and the depths. No differences were found in the leguminous tree site. There were significant differences in Ca concentration among the leguminous tree sites and no differences

were observed between the depths.There were also no significant differences in Ca in the non-leguminous tree site (Table 3 and Fig.7 and 8).

There were significant differences in Mg concentration among the locations and among depths. No significant difference were found in sodium adsorption ratio (SAR) among locations but, there were significant differences among depths, where SAR increased with depth. In the leguminous tree site, however, there were significant differences in SAR between the soil under and between the tree and the adjacent open area.

No differences in SAR were observed between depth (0-30 cm) and (30-60 cm) but both differed significantly from the third layer (60-90 cm), (Table 3 and Fig. 4)

No statistically significant differences were found in chloride (Cl) concentration between locations in the two sites, but there were significant differences between (0-30 cm) and (30-60 cm) layers where Cl decreased with depth. Also no significant differences were noted in the carbonate (CO_3^{2-}) concentration between locations in the two sites but, there were statistical differences between the first and the two other depths. SO_4^{2-} had the same trend of carbonate, but there were differences between sites where SO_4^{2-} was higher in the leguminous tree site.

No differences were found in the electrical conductivity (EC) values in the two sites, but the leguminous tree site was higher in EC values and there was significant differences between (0-30 cm) and (60-90 cm) layers where the former had higher EC in all locations.

Fig. (4) Means of pH, SAR and $CaCO_3$ in the different locations.

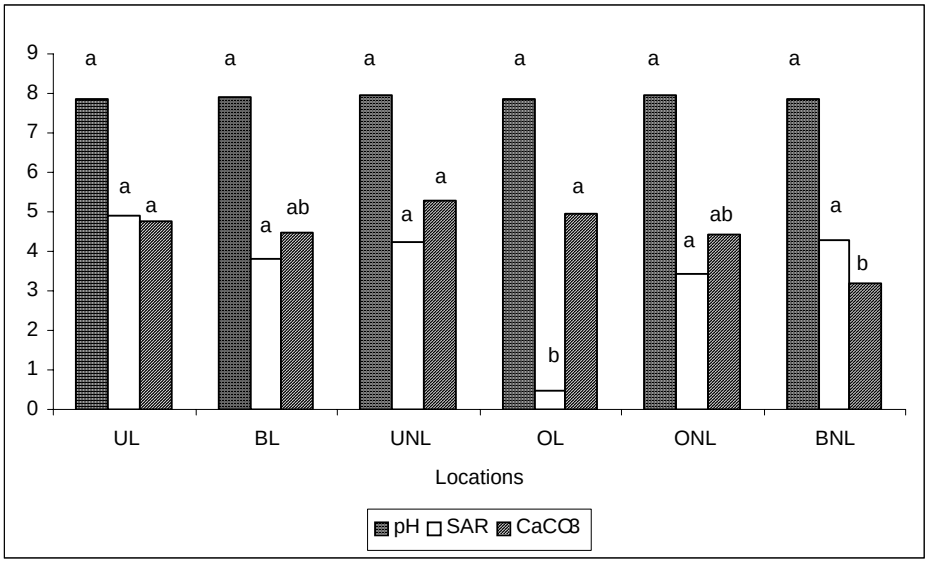


Fig.(5):Means of organic carbon, total nitrogen, organic matter and 0.5 M $NaHCO_3$ extractable phosphorus in the different locations.

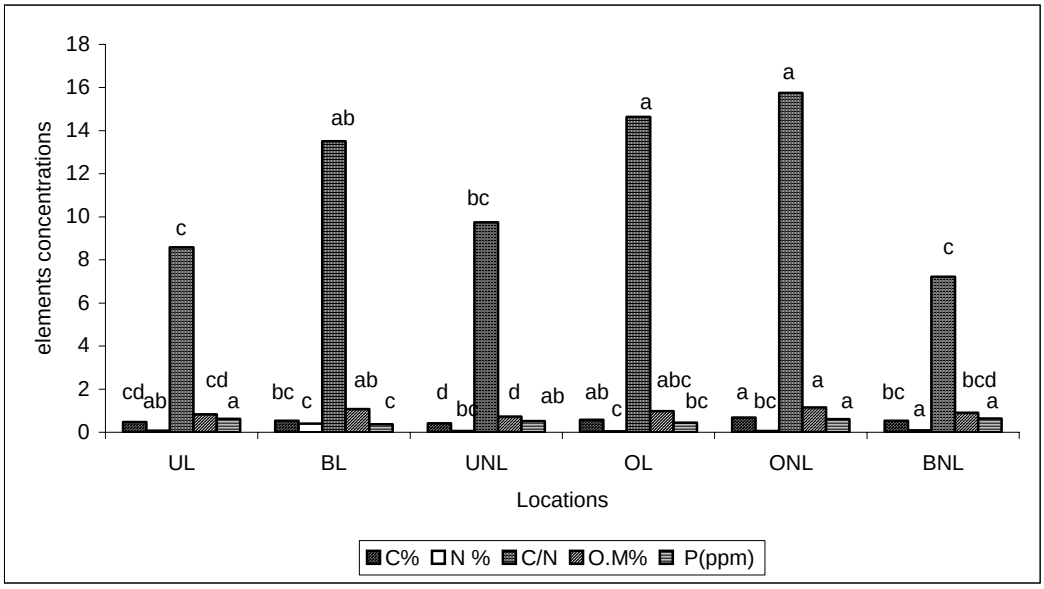


Fig.(6): Correlation between organic matter and C:N ratio in the different locations.

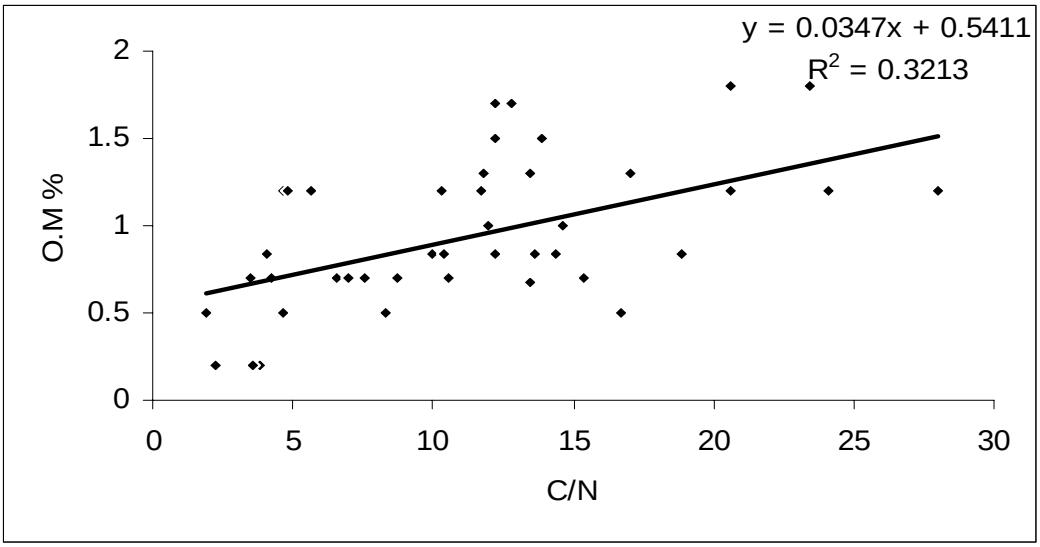


Fig.(7):Means of concentrations of soluble anions and E.C in the different locations.

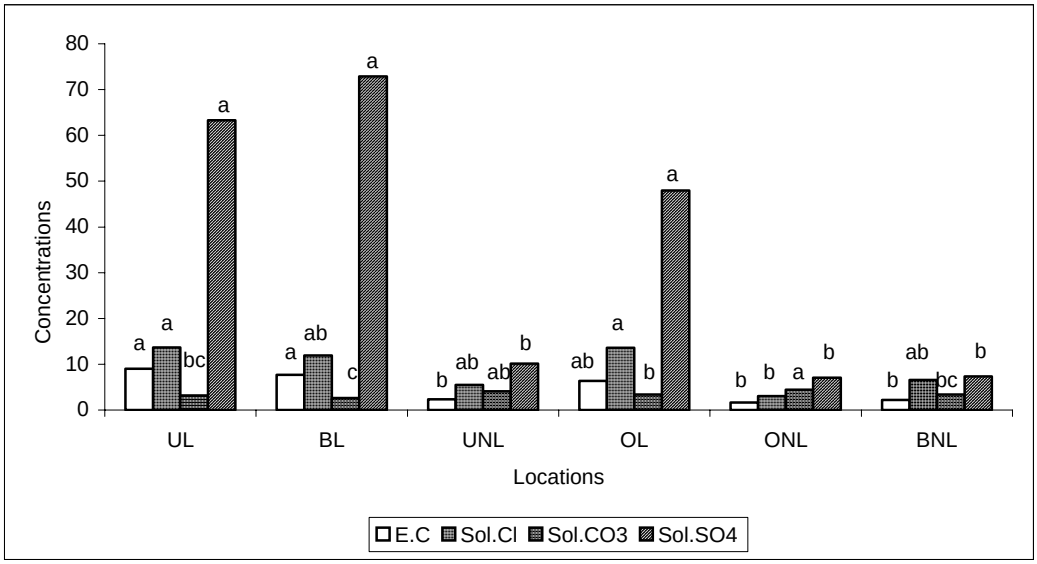
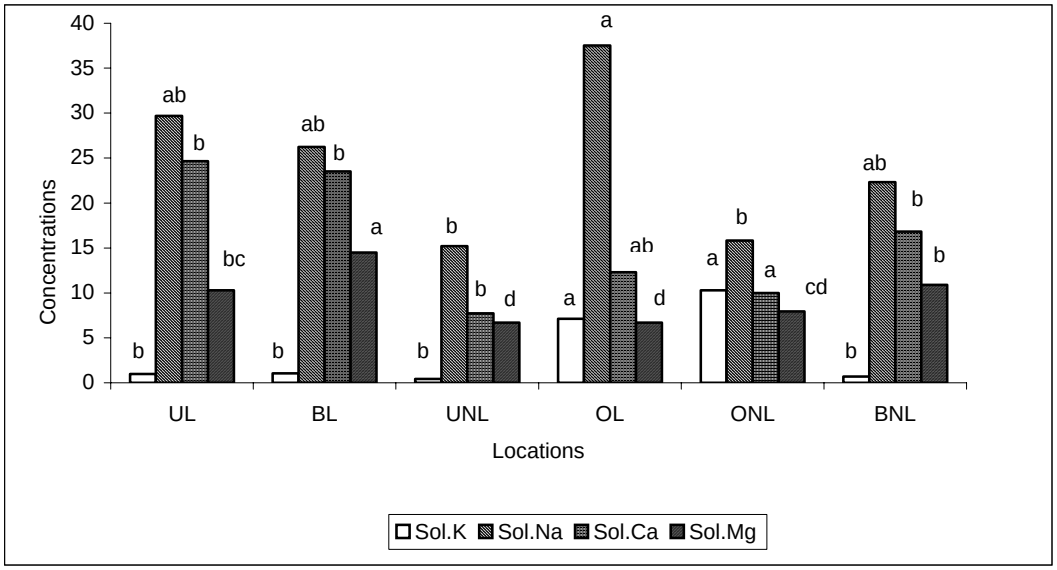


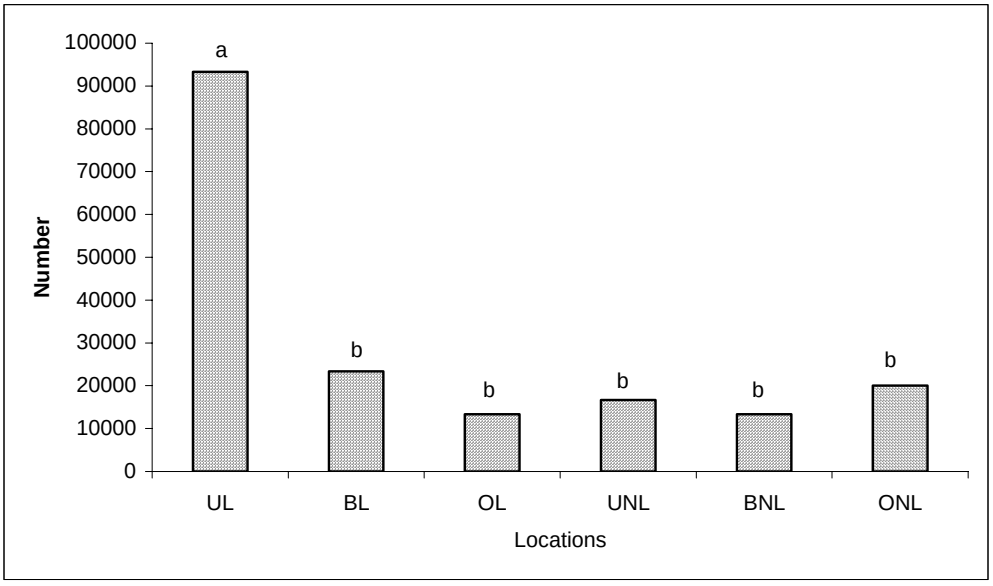
Fig.(8): Means of concentrations of soluble cations in the different locations.



4.3 Fungal numbers

Significant differences in fungal numbers were observed between locations, where fungal numbers were greater under the canopies and decreased with distance from the canopy center. Fungal numbers were greater under the *Acacia tortilis* site (Fig. 9).

Fig.(9): Mean fungal numbers in the (0-30 cm) depth in the different locations.



4.5 Plant density

Understored vegetation was 49.7 % under acacia and 0 % under the non-leguminous tree (Table 4).

Table (4): Plant density under *Acacia tortilis* and *Capparis decidua.*

Acacia tortilis	*Capparis decidua.*
49.7%	0 %

Chapter Five

DISCUSSION

5.1 Physical properties

No significant changes were observed among the locations, in soil texture and associated saturation percentage. These changes, if present, are important because they are likely to affect water availability for plants at most ranges of soil water contents. Soil moisture is considered to be a critical environmental variable affecting establishment and growth of nutrient availability (e.g., nitrogen is limiting only when water is plentiful; Fisher *et al*. 1988, Sharifi *et al*. 1988, and Lajtha and Whitford 1989).

It is obvious from the results obtained that soils under tree canopies had high aggregate stability than those between trees and in open space; however, the values are higher under *Capparis decidua*. Many factors concur to elaborate and develop soil structure under trees. Organic compounds released from litter and twigs decomposition, biological activity, root system reticulation and their exudates in addition to the mineral elements and compounds all contribute to bind the soil particles into aggregates (Armson,1977 and Duchaufour, 1984). Structural units constructed by the factors mentioned above, especially biological and biochemical, seems to have strong durable liasions. Meanwhile, in bare-land soil only the mineral elements and their compounds dominate as binding agents, particularly, ions, which cause the formation of massive structure (Fitzpatrick, 1986). Good structured soil, if found, will only be restricted to the closer proximity of the few scattered trees and shrubs, because at distal surroundings the pedoclimatic conditions are too severe to allow active biological activity. The uncovered portion of the bare land, will only harbor the kind of fauna capable to lodge

themselves deeper in the sub soil, and most of this type of fauna (crickets, rodents…etc) seem to play little in soil structure development (Nimer, 2000).

5.2 Chemical properties

The presence of more N,K^+,Ca^{2+},Cl^-,SO_4^{2-},CO_3^{2-} and 0.5 M $NaHCO_3$ extractable P in soils under the trees canopy than in between trees and open space supports the hypothesis that trees enrich the soil under their canopies at the expense of the soil nutrient capital in the open areas. Trees seem to effectively redistribute nutrients which they have absorbed throughout their rooting volume to a zone principally beneath the tree canopy where the bulk of leaves, twigs, and other plant parts fall when shed by tree. Garcia-Moya and Mc Kell (1970), Wilson,(2002), Romney *et al*.(1980), Skujins, (1981), Schlesinger *et al*. (1996), Bolling and Walker, (2002), Virginia and Jarrell, (1983), Alban, (1982), Charley and West, (1977), Nimer, (2000), Van Miegroet *et al*, (2000), and Bates *et al* (2002) observed a similar pattern of enrichment of soil nutrients mentioned above of other desert shrubs (e.g. Larrea, Juniper, and Cassia). Also, Zinke, (1962) demonstrated a significant effect of shore pine (*Pinus contorta*) on the distribution pattern of several soil properties on a coastal dune in California.

Since about 95-98 % of he N and S is tied up in organic matter, it is expected that most of the N and S to be located in the zone of concentration of organic matter or near the occurance of organic matter in the the soil of these ecosystems. The data indicated that vertical concentration gradient for N and S under the trees canopy is not as steep as that for organic matter. This is to be expected because

colloidal organic matter (humus) does not readily move downward in calcareous soils. On the other hand, the soluble products of N and S mineralization (nitrate and sulfate) can be expected to be leached downward if their availability exceeds the demands of plants and microorganisms during periods of rainfall sufficient for leaching. Interestingly, there was a significant increase in N concentration in the open soil surrounding the *Capparis decidua*. Albeit there is a possiblity of this difference being an artifact, it is likely that this may be due to the plants' activity, either through N fixation by plants growing beyond the canopy (there are no plants beneath the canopy, Table 4), or by accumulation of organic N associated with observed organic matter accumulation in the surrounding open space, or simply due to greater nitrogen depletion under the trees by uptake and subsequent repeated grazing away of tree biomass by desert animals.

Skujins (1976) presented data which showed that C/N ratio is important in desert soil because C is the energy source for nitrogen fixation and denitrification. Organic matter and C/N ratio is less under capparis as compared to legume canopies (Table 3 and Fig.6).

Despite the marked effect of trees on several soil nutrients, its effect on soil pH was not significant over the lifetime of the tree ecosystems sampled, because acidity of percolates from litter or through fall are probably not sufficient for rapid changes in soil pH in calcareous top soils (Table 3) of high buffering capacity.

The differential accumulation of litter among locations of the trees is probably responsible for the higher soluble salts in the surface layer, and the observed distribution pattern of K and P with soil depth. Potassium is readily leached from plant materials and can be expected to be leached downward more readily where the ratio of soluble salts

to cation exchange capacity is higher (Black, 1968). The distribution of P with depth is opposite that of K (i.e., amount of P declines with depth). This can be expected as the phosphate ions are relatively immobile and are not likely to move rapidly downward from the point of occurence in the soil. Differences among soil under the trees are more likely to occur on the acacia site where P via litter fall is greater. The expected higher occurence of P in the soil under acacia seems to be manifested by a trend towards differences among locations, albeit the differences were not statistically significant.

The fragmented canopies of the two species may result in increased soil temperature, and therefore, faster decomposition of organic matter, as well as lower deposition and increased mobility of litter. The increased decomposition of organic matter at higher soil temperature results in production of soluble or volatile compounds, which result in rapid loss of N from the soil. Accumulation of organic matter in open space between non-leguminous trees may be due to the wind blown litter trapped by the dense bottom of capparis bushes.

Previous reports of increased salinity (ECe) associated with plant activity have been linked to plants known to accumulate salt in leaves such as *Atriplex vesicaraia* and *Acacia senegal* (Charley and Mc Garity, 1964; and Nimer, 2000). The accumulation of solutes may be produced by a different process. It is indeed possible that the tree produces hydraulic lift, pumping the saline water from the deeper layers towards the soil surface; this could result over time in the accumulation of salts close to the surface.

Nutrient content under trees canopy has, generally, improved if compared to the bare soil. But, the extent of change was variable for individual elements, with the consequence that only some of them

showed significant differences. Several studies (Virginia and Jarrell ,1983; Alban 1982; Kieft *et al*. 1998; and Nimer 2000) showed that trees tended to accumulate elements on the soil under their canopies through the return of litter fall. Return of elements to the soil is achieved through the biochemical cycle in which roots, particularly of trees, are capable of extracting nutrients from deeper layers and wider soil mass. These elements then complete their cycle through the varied parts of the plants and return to the soil via decay of tree parts or of the whole tree after death. Therefore, removal of vegetation cover from tropical soils should seriously jeopardize their potential fertility unless otherwise rectified by fertilization to sustain future regenerations. Consequently the dewellers of these regions have adopted agroforestry as the best exploitation of these ecosystems (Nair, 1984). On drier areas such as the one under investigation the extent of these considerations are evidently less acute due to the lack of enough precipitation to provoke excessive leaching except perhaps at short moments during the peak of the rainy season. Thus, in these areas the bulk of the nutrients made available from litter and twigs decomposition will tend to be conserved in the soil during the dry period due to the absence of leaching and lack of uptake by trees because of their reduced physiological activity.

5.3 Plant Density

Large shrubs often act to ameliorate microclimatic conditions and facilitate survival and growth of plants under their canopies (Franco and Nobel 1989; Gutierrez *et al*.1993). However, shrubs may also act in a competitive manner by decreasing soil water content and light levels below their canopies (Fowler 1986; Bilbrough and

Caldwell 1995; Forseth *et al*. 2001). The canopies of *Capparis decidua* have a pronounced effect on plant density. No other species were found under *Capparis decidua*, but many species were found under *Acacia tortilis*. Amelioration of the microclimate by the trees is almost certainly an important factor determining plant density. Given that there were several localized microclimate differences between the trees (e.g., radiation, water retention, soil conditions), radiation balance may be important in determining community composition (Callaway *et al*. 1991).

5.4 Fungal numbers

The data concerning fungal numbers supported the findings of Charley and Cowling, (1968) who found a rhizosphere effect that stimulated microbial growth surrounding the root. The tree roots may release exudates, secretions, and plant mucilage (Metting, 1993). These organic compounds are consumed as energy source for microorganisms, to sustain their life and activities. Consequently, the soil microbes would be more active, eventhough, the rhizosphere effect may vary according to the tree species, stage of plant development, and soil micro-environmental conditions (Smith *et al*.,1998). Overall results of this experiment have shown that soil physical, chemical and probably micro-environmental conditions (through shading) seemed to be more favourable under *Acacia tortilis* as compared to *Capparis decidua* and hence fungal activity was found several times higher under the first as compared to the latter.

Chapter Six

SUMMARY, CONCLUSION AND RECCOMMENDATIONS

The data of this study demonstrated a distribution pattern of soil properties within the zone of influence of tree canopies. There is a strong indication that trees are the causal agent of the patterns observed and that they function to improve soil conditions beneath their canopies as compared to the soil between trees and open space. Many of the physical, chemical and biological impacts of tree islands in soils in arid and semi-arid regions are intimately linked to the accumulation and distribution of organic matter in and around the tree islands. The dynamics of both may play a significant role in maintaining conditions that favor regeneration and growth of trees in an otherwise austere environment. Through shading, tree islands tend to improve and extend late-summer (Kharief) soil moisture conditions by slowing down evaporative water losses. This higher water availability in early Kharief, coupled with more moderated soil temperatures, would be expected to favorably enhance biological processes.

It has been found in this study that the presence of trees induced greater C sequestration in the above ground biomass and C cycling through litter fall, which may have locally improved physical, chemical and biological attributes of soil fertility, especially in the surface soil. With the enrichment of C in the surface soil a distinct change in nutrient distribution and availability inside the tree islands occured that further accentuated differences in fertility status compared with the surrounding soils. These differences in soil organic matter may also influence water-holding capacity, especially in the surface soil. The improved soil physical conditions, coupled with higher availability of nutrients under the tree canopy, explains the abundance and improved growth of perennial grasses observed under acacia (Table 4) which was in line with the findings of Tiedmann and

Klemmedson (1973), Charley and West (1975 &1977), Alban (1982), Parker (1982), Evertt (1986), Gutierrez *et al*. (1993), Schlesinger *et al* (1996), Kieft *et al*. (1998), Facelli and Daniel (2000), Van Miegroet *et al*. (2000), Bates *et al*. (2002), Bolling and Walker (2002), and Wilson (2002). The findings can summerised as follows:

- Soils under acaica not only had greater C and N concentrations than adjacent capparis soils, but also greater soluble cations and anions and more microbial numbers.
- Soils under *Capparis* sp had more stable soil aggregates.
- Change in C with depth and distance from the tree were much less pronounced than that reported in other studies.
- Sub-canopy soils beneath the trees are nutrient enriched.
- Soil texture, moisture content and saturation percentage did not differ significantly between the two sites (leguminous and nonleguminous).
- Long-lived trees may act as bio-accumulators of nutrients, generating high productivity patches.But the effectiveness of different tree species differ in this respect. This is likely to occur not just by passively retaining redistributed nutrients, but also by accumulating around them nutrients obtained by roots extending away from the canopy, or from deeper layers of soil. This last process, together with fixation of atmospheric N, should result in an overall increase in the nutrient availability in the ecosystem. By creating this spatial heterogeneity it could enhance the system's biodiversity and by modulating the nutrient dynamics, it can control the productivity of the system.
- The species differences is manifested primarily in the horizontal gradients. That is, the decline of most nutrients with distance from the under the canopy to the open area, which was more in *Acacia tortilis* than in *Capparis decidua* for all soil layers. Decline in most nutrients with depth (from the surface to 60-90 cm) was similar for both species.

- Microbial activity also shows a gradient under the shrubs. Higher microbial activity enhanced by more favorable microenvironments under shrubs would facilitate litter decomposition and nutrient transfer into the soil.
- It is clearly important to investigate the population structure of key tree species so as to reveal thier role in generating spatial heterogeneity. The characteristics of an arid area depends on such patchiness (nutrient – rich islands).
- It seems that phosphate and nitrogen may be limiting for plant growth in the studied environment, thus, nutrient amendment strategies should be considered in any range productivity enhancement to assure that as many limiting factors as possible are offset. Soil nutrient levels can be managed by fertilization.

RECCOMMENDATIONS

- Identifying the mechnisms by which different tree speicies change soil chemistry is nessary to predict the effects of natural and anthropogenic disturbances on nutrient cycling.
- More information is needed to understand:
  a) the relationship between biological characteristics of different species and the intensity and persistence of changes produced, and
  b) responses of the species, that live in different microenvironments, to the environmental changes. Noy-Meir, (1981) proposed that water and nutrients in arid lands are usually at such low levels that plants are unable to use them (i.e. they are below the critical threshold). According to this model the accumulation of resources in patches via water runoff carrying nutrients to depressions concentrates them at levels that may make them useful for plants (i.e. above the minimum threshold).This is because the non linear responses of net primary productivity in enriched patches is larger than the reduction produced by the loss of resources from the source area. As a consequence, total productivity should be higher in heterogeneous environments than in environments with a homogeneous resource distribution (Noy-Meir, 1981).

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Table (2): Some physical characteristics of the soil of the study area under and between *Acacia tortilis* and *Capparis decidua* and in adjacent open area

Location	Soil depth (cm)	M.C %	S.P	Clay %	Silt %	Sand %	Textural class	Aggregate stability %
UL	0-30	3.57 b	55.1 b	42.5 b	19.0 c	38.5 a	Clay	8.4 b
	30-60	4.17 a	55.3a b	42.6 b	23.8 b	33.6 b	Clay	
	60-90	4.23 a	61.67 a	53.5 a	20.5 a	26.0 c	Clay	
BL	0-30	3.13 b	52.93 b	40.1 b	19.2 c	41.7 a	Clay	4.4 c
	30-60	4.23 a	53.3 ab	40.0 b	20.0 b	40.0 b	Clay	
	60-90	4.17 a	54.67 a	43.7 a	26.3 a	30.0 c	Clay	
UNL	0-30	3.17 b	56.37 b	41.4 b	17.9 c	40.7 a	Clay	17.6 a
	30-60	3.6 a	55.0 ab	41.9 b	27.3 b	30.8 b	Clay	
	60-90	3.93 a	56.83 a	44.1 a	29.8 a	26.1 c	Clay	
OL	0-30	2.97 b	52.93 b	42.1 b	13.6 c	44.3 a	Clay	3.0 c
	30-60	3.4 a	52.77 a b	42.0 b	13.9 b	40.1 b	Clay	
	60-90	4.3 a	55.97 a	43.5 a	26.0 a	30.5 c	Clay	
ONL	0-30	3.87 a	52.77 b	40.4 b	16.7 c	42.9 a	Clay	2.9 c
	30-60	3.6 a	55.07 a b	44.6 b	15.0 b	40.4 b	Clay	
	60-90	2.77b	51.8 a	45.0 a	23.7 a	31.3 c	Clay	
BNL	0-30	2.93 b	52.5 b	41.0 b	17.9 c	41.1 a	Clay	5.5 c
	30-60	3.4 a	57.9 ab	41.5 b	21.8 b	36.7 b	Clay	
	60-90	3.23 a	58.33 a	44.6 a	22.1 a	33.3 c	Clay	

Different letters along the same column indicate significant differences according to Duncan Multiple Range Test..

Table (3): Means of the chemical characteristics of the soil of the studied area under and between *Acacia tortilis* and *Capparis decidua* and in adjacent open area.

cation	Soil depth (cm)	pH	Soluble K^+ meq/l	Soluble Na^+ meq/l	Soluble Ca^{2+} meq/l	Soluble Mg^{2+} meq/l	SAR	Soluble Cl meq/L	Soluble SO4-- meq/L	Soluble CO3-- meq/L	C %	N%	C/N	O.M %	$NaHCO_3$ P (ppm)	CaC(%
	0-30	7.9^{ab}	5.51^{b}	28.1^{a}	29.83^{a}	22.67^{a}	5.5^{b}	15.19^{a}	90.13^{a}	4.07^{a}	0.71^{a}	0.063^{a}	11.28^{a}	1.6^{a}	0.61^{a}	6.4^{a}
BL	30-60	7.8^{b}	0.77^{b}	33.6^{a}	27.5^{a}	11.5^{a}	7.6^{a}	7.83^{b}	51.56^{b}	2.03^{b}	0.68^{a}	0.032^{b}	21.55^{a}	1.23^{a}	0.30^{b}	3.2^{b}
	60-90	8.0^{a}	1.88^{b}	33.9^{a}	23.17^{a}	21.33^{a}	7.2^{a}	12.79^{ab}	63.9^{b}	1.87^{b}	0.20^{b}	0.026^{c}	7.69^{b}	0.37^{b}	0.22^{c}	3.8^{b}
	0-30	7.9^{ab}	0.86^{b}	13.3^{b}	15.5^{b}	12.83^{a}	3.5^{b}	8.03^{a}	10.67^{a}	5.1^{a}	0.60^{a}	0.13^{a}	3.37^{b}	1.03^{a}	0.97^{a}	4.4^{a}
NL	30-60	7.8^{b}	0.60^{b}	23.3^{b}	20.67^{a}	12.00^{a}	5.8^{b}	4.02^{b}	5.33^{b}	2.55^{b}	0.57^{a}	0.067^{b}	8.65^{a}	0.97^{a}	0.49^{b}	2.2^{b}
	60-90	7.9^{a}	0.60^{b}	30.3^{a}	14.33^{b}	7.83^{a}	9.2^{a}	7.64^{ab}	6.13^{b}	2.45^{b}	0.43^{b}	$0.0.57^{c}$	9.65^{a}	0.73^{b}	0.45^{c}	3.0^{b}
	0-30	8.0^{ab}	14.14^{a}	30.03^{a}	16.33^{b}	5.30^{a}	9.1^{a}	14.69^{a}	58.2^{a}	6.03^{a}	0.81^{a}	0.063^{b}	13.04a	1.34^{a}	0.70^{a}	7.2^{a}
OL	30-60	7.7^{b}	2.43^{b}	19.93^{b}	12.0^{b}	5.45^{a}	6.6^{b}	7.34^{b}	29.1^{b}	2.35^{b}	0.42^{a}	0.031^{c}	13.5^{a}	0.84^{a}	0.35^{b}	3.6^{b}
	60-90	8.0^{a}	14.75^{a}	62.63^{a}	14.5^{b}	9.33^{a}	17.9^{a}	18.82^{ab}	56.5^{b}	1.83^{b}	0.52^{b}	0.031^{c}	17.36^{a}	0.73^{b}	0.28^{c}	4.1^{b}
	0-30	7.9^{ab}	13.34^{a}	26.90^{b}	17.83^{a}	9.67^{a}	7.3^{a}	5.06^{a}	12.73^{a}	6.4^{a}	0.60^{a}	0.09^{a}	6.90^{b}	1.2^{a}	0.99^{a}	5.73^{a}
)NL	30-60	7.9^{b}	17.33^{a}	12.77^{b}	8.50^{b}	8.83^{a}	4.4^{b}	2.53^{b}	6.37^{b}	3.2^{b}	0.73^{a}	0.045^{b}	16.23^{a}	1.2^{a}	0.50^{b}	2.87^{b}
	60-90	8.0^{a}	0.19^{b}	7.77^{b}	3.67^{b}	5.33^{a}	3.7^{b}	1.51^{ab}	2.2^{b}	3.8^{b}	0.70^{b}	0.029^{c}	24.14^{a}	1.03^{b}	0.32^{c}	4.73^{b}
	0-30	7.9^{ab}	1.89^{b}	12.13^{b}	25.17^{a}	8.00^{a}	3.0^{b}	24.14^{a}	6.5^{a}	4.73^{a}	0.68^{a}	0.14^{a}	5.04^{b}	1.2^{a}	1.23^{a}	7.53^{a}
UL	30-60	7.8^{b}	0.51^{b}	28.53^{b}	21.83^{a}	10.17^{a}	7.1^{a}	8.08^{b}	35.5^{b}	2.37^{b}	0.49^{b}	0.045^{b}	10.89^{a}	0.84^{a}	0.41^{b}	3.77^{b}
	60-90	7.9^{a}	0.51^{b}	48.43^{a}	27.0^{a}	12.67^{a}	10.8^{a}	8.88^{ab}	47.87^{b}	2.38^{b}	0.27^{b}	0.034^{c}	9.81^{a}	0.47^{b}	0.25^{c}	3.03^{b}
	0-30	7.8^{ab}	0.51^{b}	14.27^{b}	8.00^{b}	8.67^{a}	4.9^{b}	7.51^{a}	16.63^{a}	5.97^{a}	0.53^{a}	0.071^{a}	9.17^{a}	0.9^{a}	0.77^{a}	8.0^{a}
JNL	30-60	8.0^{b}	0.43^{b}	14.33^{b}	10.67^{b}	6.83^{a}	4.8^{b}	3.75^{b}	8.43^{b}	3.00^{b}	0.47^{a}	0.039^{b}	14.45^{a}	0.8^{a}	0.39^{b}	4.0^{b}
	60-90	8.0^{a}	0.34^{b}	$23s.03^{b}$	8.50^{b}	4.50^{a}	9.2^{a}	5.1^{ab}	5.17^{b}	3.32^{b}	0.27^{b}	0.046^{c}	5.63^{b}	0.47^{b}	0.41^{c}	3.8^{b}

Different letters along the same column indicate significant differences according to Duncan Multiple Range Test.

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Appendix (1): pH ANOVA

Source	d.f	ANOVA SS	Mean Square	F value	Pr > F
Treatment	5	0.0564814 8	0.0112963 0	0.39ns	0.849 2
Block	2	0.0625925 9	0.0312963 0	1.09	0.353 3
Treatment * Block (Error a)	10	0.2062963 0	0.0206296 3	0.72ns	0.701 3
Depth	2	0.1614814 8	0.0807407 4	2.80ns	0.080 5
Treatment * Depth	10	0.2074074 1	0.0207407 4	0.72ns	0.698 0
Error b	24	0.6911111 1			
Total	53	1.3853703 7			

Appendix (2): Moisture Content ANOVA

Source	**d.f**	**ANOVA SS**	**Mean Square**	**F value**	**Pr > F**
Treatment	5	3.76592593	0.75318519	2.31ns	0.0759
Block	2	2.05481481	1.02740741	3.15ns	0.0611
Treatment* Block (Error a)	10	7.6562 9630	0.76562963	2.35	0.0424
Depth	2	2.78481481	1.39240741	4.26*	0.0260
Treatment* Depth	10	6.27962963	0.62796296	1.92	0.0919
Error b	24	7.83551852			
Total	53	30.377			

Appendix (3): Soluble K^+ ANOVA

Source	**d.f**	**ANOVA SS**	**Mean Square**	**F value**	**Pr > F**
Treatment	5	799.3359919	159.8671984	3.92**	0.0097
Block	2	293.9207074	146.9603537	3.60	0.0428
Treatment* Block (Error a)	10	607.4591861	60.7459186	1.49*	0.2035
Depth	2	6.3626341	3.1813171	0.08*	0.9252
Treatment* Depth	10	795.4747794	79.5474779	1.95	0.0873
Error b	24	981.6352411			
Total	53	3481.188540			

Appendix (4): Soluble Na^+ ANOVA:

Source	**d.f**	**ANOVA SS**	**Mean Square**	**F value**	**Pr > F**
Treatment	5	3297.0883148	659.416630	2.89*	0.0351
Block	2	942.597037	471.298519	2.07	0.1486
Treatment* Block (Error a)	10	3168.2652963	316.826296	1.39*	0.2438
Depth	2	2869.038148	1434.519074	6.29**	0.0064
Treatment* Depth	10	4482.315185	448.231519	1.97	0.0850
Error b	24	5473.5525			
Total	53	20232.85648			

Appendix (5): Soluble Ca^{2+} ANOVA

Source	**d.f**	**ANOVA SS**	**Mean Square**	**F value**	**Pr > F**
Treatment	5	2252.38889	450.47778	9.82**	0.0001
Block	2	256.083333	128.041667	2.79	0.0813
Treatment* Block (Error a)	10	957.861111	95.786111	2.09*	0.0678
Depth	2	29.083333	14.541667	0.32ns	0.7313
Treatment* Depth	10	575.861111	57.586111	1.26	0.3083
Error b	24	1100.722222			
Total	53	5172.0000			

Appendix (6): Soluble Mg^{2+} ANOVA

Source	**d.f**	**ANOVA SS**	**Mean Square**	**F v**
Treatment	5	412.6164444	82.5232889	8.2
Block	2	23.82281111	11.9114056	1.1
Treatment* Block (Error a)	10	66.1262778	6.6126278	0.6
Depth	2	12.1905778	6.0952889	0.6
Treatment* Depth	10	363.9884444	36.3988444	3.6
Error b	24	240.9101775		
Total	53	1119.6547333		

Appendix (7): SAR ANOVA

Source	**d.f**	**ANOVA SS**	**Mean Square**	**F value**	**Pr > F**
Treatment	5	111.7396981	22.3479396	8.39**	0.0001
Block	2	4.1776704	2.0888352	0.78	0.4678
Treatment* Block (Error a)	10	75.9975519	7.5997552	2.85**	0.0172
Depth	2	43.5845481	21.7922741	8.18**	0.0020
Treatment* Depth	10	81.7542074	8.1754207	3.07	0.0118
Error b	24	63.9169778			
Total	53	381.1706537			

Appendix (8): C % ANOVA

Source	**d.f**	**ANOVA SS**	**Mean Square**	**F value**	**Pr > F**
Treatment	5	0.34986111	0.06997222	2.43*	0.0644
Block	2	0.21333333	0.10666667	3.70	0.0396
Treatment* Block (Error a)	10	0.08888889	0.00888889	0.31ns	0.9715
Depth	2	0.41063333	0.20531667	7.13**	0.0037
Treatment* Depth	10	0.77852222	0.07785222	2.70	0.0223
Error b	24	0.699111112			
Total	53	2.53235000			

Appendix (9): N % ANOVA

Source	d.f	ANOVA SS	Mean Square	F value	Pr > F
Treatment	5	0.011416483	0.00283297	42.76**	0.0001
Block	2	0.00016211	0.00008106	1.22	0.3119
Treatment* Block (Error a)	10	0.00457722	0.00045772	6.91**	0.0001
Depth	2	0.03357011	0.01675506	252.91**	0.0001
Treatment* Depth	10	0.007796656	0.00077966	11.77	0.0001
Error b	24	0.004108367			
Total	53	0.06180083			

Appendix (10): C/N ANOVA

Source	**d.f**	**ANOVA SS**	**Mean Square**	**F value**	**Pr > F**
Treatment	5	556.5449103	111.3089821	6.34**	0.0007
Block	2	81.9215694	40.9607847	2.33	0.1187
Treatment* Block (Error a)	10	155.4512350	15.5451235	0.88*	0.5598
Depth	2	349.8530868	174.9265434	9.96**	0.0007
Treatment* Depth	10	685.6527621	68.5652762	3.90	0.0030
Error b	24	421.6115054			
Total	53	2251.035069			

Appendix (11): O.M% ANOVA

Source	d.f	ANOVA SS	Mean Square	F value	Pr > F
Treament	5	1.06679259	0.21335852	2.29*	0.0773
Block	2	0.38640370	0.19320185	2.08	0.1472
Treatment* Block (Error a)	10	0.31104074	0.03110407	0.33ns	0.9626
Depth	2	1.38152593	0.69076296	7.43**	0.0031
Treatment* Depth	10	3.05225185	0.30522519	3.28	0.0083
Error b	24	2.23225823			
Total	53	8.43023704			

Appendix (12): Total P ANOVA

Source	d.f	ANOVA SS	Mean Square	F value	Pr > F

Treament	5	0.51932037	0.10386407	29.12**	0.0001
Block	2	0.02800370	0.01400185	3093	0.0335
Treatment* Block (Error a)	10	0.13372963	0.01337296	3.75**	0.0039
Depth	2	3.25207037	1.62603519	455.90**	0.0001
Treatment* Depth	10	0.47659630	0.04765963	13.36	0.0001
Error b	24				
Total	53	4.49532037			

Appendix (13): Soluble Cl^- ANOVA

Source	d.f	ANOVA SS	Mean Square	F value	Pr > F
Treament	5	955.3589037	191.0717807**	4.89**	0.0032
Block	2	78.1355815	39.0677907	1.00	0.3831
Treatment* Block (Error a)	10	743.6885074	74.3688507	1.90ns	0.0957
Depth	2	421.7571704	210.8785852	5.39*	0.0116
Treatment* Depth	10	428.2693852	42.8269385	1.09	0.4042
Error b	24	938.7184448			
Total	53	3565.927993			

Appendix (14): Soluble CO_3^{2-} ANOVA

Source	df	ANOVA SS	Mean Square	F value	Pr > F
Treatment	5	19.25959259	3.85191852	19.59**	0.0001
Block	2	0.39272593	0.19636296	1.00	0.3831
Treatment* Block (Error a)	10	7.71629630	0.77162963	3.92**	0.0029
Depth	2	93.28467037	46.64233519	237.25**	0.0001
Treatment* Depth	10	5.17168519	0.51716852	2.63	0.0254
Error b	24	4.71837772			
Total	53	130.5433481			

Appendix (15): Soluble $CaCO_3$ ANOVA

Source	d.f	ANOVA SS	Mean Square	F value	Pr > F
Treatment	5	23.0814815	4.6162963	3.83**	0.0108
Block	2	8.1170370	4.0585185	3.37	0.0514
Treatment* Block (Error a)	10	18.9496296	1.8949630	1.57*	0.1751
Depth	2	112.7781481	56.3890741	46.80**	.00001
Treatment* Depth	10	16.3751852	1.6375185	1.36	0.2572
Error b	24	28.9200001			
Total	53	208.2214815			

Appendix (16): Soluble SO_4^{2-} ANOVA

Source	**d.f**	**ANOVA SS**	**Mean Square**	**F value**	**Pr > F**
Treatment	5	41057.81426	8211.56285	16.92**	0.0001
Block	2	387.06815	193.53407	0.40	0.6755
Treatment* Block (Error a)	10	8975.51852	897.55185	1.85ns	0.1053
Depth	2	7910.51704	3955.25852	8.15**	0.0020
Treatment* Depth	10	7104.06296	710.40630	1.46	0.2132
Error b	24	11646.96666			
Total	53	77081.94759			

Appendix (17): E.C ANOVA

Source	d.f	ANOVA SS	Mean Square	F value	Pr > F
Treatment	5	460.9053704	92.1810741	13.38**	0.0001
Block	2	22.9970370	11.4985185	1.67	0.2096
Treatment* Block (Error a)	10	183.0518519	18.3051852	2.66*	0.0243
Depth	2	160.9792593	80.4896296	11.68**	0.0003
Treatment* Depth	10	113.3296296	11.3329630	1.64	0.1535
Error b	24	165.3777768			
Total	53	1106.6409259			

Appendix (18): Clay % ANOVA

Source	**d.f**	**ANOVA SS**	**Mean Square**	**F value**	**Pr > F**
Treament	5	126.955	25.391	3.61**	0.0141
Block	2	37.1811111	18.5905556	2.64	0.0917
Treatment* Block (Error a)	10	82.2922222	8.2292222	1.17*	0.3566
Depth	2	203.2477778	101.6238889	14.45**	0.0001
Treatment* Depth	10	140.5388889	14.0538889	2.00	0.0800
Error b	24	168.75333333			
Total	53	758.9683333			

Appendix (19): Silt % ANOVA

Source	d.f	ANOVA SS	Mean Square	F value	Pr > F
Treatment	5	295.4075926	59.0815185	3.8*	0.0113
Block	2	41.9214815	20.9607407	1.35	0.2790
Treatment* Block (Error a)	10	113.0562963	11.3056296	0.73ns	0.6928
Depth	2	490.5781481	245.2890741	15.76**	0.0001
Treatment* Depth	10	327.2862963	32.7286296	2.10	0.0660
Error b	24	373.5355516			
Total	53	1641.785370			

Appendix (20): Sand % ANOVA

Source	d.f	ANOVA SS	Mean Square	F value	Pr > F
Treatment	5	286.852037	57.370407	8.56**	0.0001
Block	2	26.229259	13.114630	1.96	0.1631
Treatment* Block (Error a)	10	70.524074	7.052407	1.05ns	0.4328
Depth	2	1303.340370	651.670185	97.52**	0.0001
Treatment* Depth	10	92.792963	9.279296	1.39	0.2455
Error b	24	160.773334			
Total	53	1940.512037			

Appendix (21): Saturation Percentage ANOVA

Source	d.f	ANOVA SS	Mean Square	F value	Pr > F
Treatment	5	131.2066667	26.2413333	1.79ns	0.1525
Block	2	40.6177778	20.3088889	1.39	0.2691
Treatment* Block (Error a)	10	164.2155556	16.4215556	1.12ns	0.3868
Depth	2	70.5233333	35.2616667	2.41ns	0.1114
Treatment* Depth	10	123.79	12.379	0.85	0.5921
Error b	24	351.3666666			
Total	53	881.72			

Appendix table (22): Fungal Number ANOVA:

Source	**d.f**	**ANOVA SS**	**Mean Square**	**F value**	**Pr > F**
Treatment	5	3.34014E+10	6.68029E+09	0.75	0.5960
Block	2	1.50604E+09	7.53019E+08	0.08	0.9195
Treatment* Block (Error a)	10	1.16671E+11	1.16671E+10	1.31	0.2828
Depth	2	2.94823E+11	1.47412E+11	16.49	0.0001
Treatment* Depth	10	1.24096E+11	1.24096E+10	1.39	0.2442
Error b	24				
Total	53	7.85033E+11			

Appendix (23): Aggregate Stability % ANOVA

Source	d.f	ANOVA SS	Mean Square	F value	Pr > F
Treatment	6	517.1111111	86.1851852	46.57	0.0001
Error a	11	20.3583333	1.8507576		
Total	17	537.4694444			